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RESEARCH ARTICLE

The Effect of Creasing Lines on the Compression Strength of Adjustable Height Corrugated Boxes

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ABSTRACT

Due to its high strength and low density, the corrugated fibreboard (CFB) box is one of the most popular types of packaging all over the world. This packaging device is able to fulfil a huge number of requirements of the logistic process, during the phases of handling, shipping and storage. In addition to this, corrugated packaging is easily machinable, so it is also suitable for special supply chains and products. These special needs include the requirement to fit to the inner measurements of the shipping device, e.g. the shipping container. This is particularly expected in case of less than container-load (LTL) shipments, where the shipping cost is usually based on the required area (m2) or cubic capacity (m3) of the container, so the useful filling of the shipping device is a very strong advantage. Naturally, this is easily solvable with different CFB boxes which have different heights, but this way the user needs to stock a high variety of boxes, requires a good relationship and cooperation between the parties and also a proper knowledge of product organisation in each box version. The multi-depth corrugated boxes are a suitable solution for resolving this problem. These boxes are creased at multiple intervals, so they are easily cuttable to the desired various heights. But the pre-scored lines can cause a loss of the compression strength capability of the box and thereby can lead to damages. The aim of this paper is to determine the effect of multiple creasing lines on the compression strength of the CFB box. This paper does not focus on the effect of either different creasing parameter, such as depth and width, nor on the distances between each creasing. Based on the test results, the compression strengths are decreased nearly significantly due to the additional creasing line(s).

KEY WORDS: *Packaging, Multi-depth corrugated box, LTL shipment, Box compression*

1.0 INTRODUCTION

Corrugated fibreboard is the most popular packaging material in the world [1]. There are several types of corrugated fibreboard packaging, such as trays, dividers and display stands, but the most widely used type is the box [2]. About 80% of the total quantity of paper-based packaging consisted of corrugated boxes in the USA in 2013 [3] due to the remunerative qualities during the storage and the distribution processes. These packaging devices are usually stacked during logistics operations in order to minimise the shipping costs, but their main function is to support loads and to protect the product [4]. There are lots of papers, which researched the issue of the compression strength of the corrugated box. According to McKee there is a correlation between material and geometrical properties of corrugated boxes and its stiffness, using a formula to determine the Box Compression Test (BCT) value of boxes from Edge Crush Test (ECT) value, experimentally determined constants and the perimeter of boxes [5]. Nowadays, researchers often apply finite element methods in their publications, like Biancolini and Brutti [6] and focus on the buckling behaviour of corrugated paper packages. Marcondes investigated the effect of load histories (static and dynamic) on the compression strength and shock absorption properties of corrugated fibreboard boxes [7]. Frank focused on the process of box compression and the utility of box compression testing. In his review he also examined the validity of the box compression test results to the field performance of boxes in unit loads [3]. Naturally, it is a well-known concept that moisture can affect the mechanical properties of paper. Murao [8], Paunonen and Gregersen [9] also investigated this factor in their studies. Other researchers focused on the long-term compression strength of corrugated boxes or observed the deformation of boxes during static and dynamic load [10]. Aboure et al. [11] have studied the mechanical behaviours of these packaging structures under static compression. Beside these papers, several associations offer test standards to assess the compression strength of packaging materials made of corrugated cardboard sheet [12-15]. As it can be seen from these papers, the box compression is a popular, well-developed field of packaging. However, the specialities of the packaged product or the handling recommendations may require packaging devices with special properties. Corrugated boxes sometimes have ventilation and hand holes to permit air circulation or to improve the manual handling of the boxes. The effects of these modifications to the compression strength of the box were also investigated in other papers [16-18].

The specialities of the supply chain are also able to affect the packaging requirements. Due to the global expansion of transportation and handling companies, the distribution and supply chains of both raw materials and finished products have caused a significant increase in global trade. It has to be recognised that most of the shipments representing the above volume are usually “less than truckload” or “less than container-load” (LTL) units [19]. The shipping cost is usually based on the required area (m2) or cubic capacity (m3) of the container, because utilising of maximum height is a very important requirement. Boxes with the same perimeter, but a different height can solve this problem. However, this method also has some disadvantages. For example, it requires a high variety stock of boxes, good partnership and cooperation between the parties and a proper knowledge of product organisation in each box version.

The Multi-Depth Cardboard Box is a way to provide the full container capacity without the latter disadvantages. This way, the box has more creasing lines, thus different heights can be set for boxes. It is enough to have only one multi-depth

Figure 1: Inner (A) and outer (B) views of the multi-depth box

box type with the same perimeter, and a smaller height can easily be made with a cutting at the pre-scored creasing lines. Figure 1 shows these creasing lines.

Naturally, the final height of a given box depends on the distance and the number of the creasing lines. It is obvious that the weakening on the surface could affect the strength of the box, which is also influenced by the basic properties of creasing, such as the depth and the width thereof. Of course, the number of creasings and the distance between them are also influencing factors. Previous studies investigated the effect of creasing and/or folding with numerical and experimental methods, but only regarding the aspect of pure material compared to the paperboard [20-23]. On the contrary, this paper studied the effect of further creasing lines on the compression strength of the box. The goal of this paper is to attempt to identify how strength changes at the different creasing points. This way the packaging engineers can be supported with new information regarding the design of cost-efficient boxes for LTL shipment with suitable box compression strength, in cases of transportation where multi-depth boxes can be applied.

2.0 MATERIALS AND METHOD

2.1 Materials

All corrugated box samples for this study were designed using IronCad software and cut out using a ZündG3 XL 1600 plotter (Zünd Systemtechnik AG, Altstätten, CH). Two different kinds of box sizes were used for this study, the half and full pallet sizes. The exact corrugated fibreboard quality for this study can be found in Table 1. Both the bursting test and ECT results are averaged on the five samples tested.

All samples were conditioned at 23±1 °C and 50% relative humidity for 48 hours prior to testing, in accordance with the standard D4332 of the American Society of Testing Materials (ASTM) [24]. Five replicates for all types and all versions (total of 80 pieces boxes) were tested for compression strength. Compression tests were conducted using an Instron 5967 compression tester (Instron, Norwood, MA, USA) and in accordance with ASTM D642 [13]. The preload of 22.68 kgf (50 lbf) was applied to all specimens prior to observing the compression strength values, and then the fixed-plates mode was applied to conduct testing at the speed of 12.7 ±2.5 mm/min (0.5 ± 0.1 in.) until failure was observed.

Table 1: Samples used for testing

	CFB quality	Mass [g/m²]	Bursting strength [kPa]	ECT [kN/m]	Version	Numbers of creasing	Inner size (LxWxH) [mm]
Type 1	444S BC	916	1000	11.5	a	3	1140x760x 640
					b	2	1140 x 760 x 575
					c	1	1140 x 760 x 510
					d	0	1140 x 760 x 445
Type 2					a	3	770 x 570 x 490
					b	2	770 x 570 x 425
					c	1	770 x 570 x 360
					d	0	770 x 570 x 295
Type 3	38 BC	936	2100	12.0	a	3	1140x760x 640
					b	2	1140 x 760 x 575
					c	1	1140 x 760 x 510
					d	0	1140 x 760 x 445
Type 4					a	3	770 x 570 x 490
					b	2	770 x 570 x 425
					c	1	770 x 570 x 360
					d	0	770 x 570 x 295

2.2 Creasing

To achieve the original aim of this study, four types of multi-depth boxes were created with two different cardboard qualities (444S BC, 38 BC) and two different geometrical variations (half and full pallet sizes), and three creasing lines with the depth and width of 2 mm and10 mm. The distance between the creasings was 65 mm.

2.3 Method

Nevertheless, our study has some limitations. It is an agreed concept that the height of the box can affect the box compression value, because the panels of the box can bulge outward whenever it is high enough [25]. In our paper the actual measured sample was compared to a control sample, which means an original height without creasing. This way, there were 65 mm, 130 mm and finally 195 mm gaps between their heights. Figure 2 shows the details of the height differences of the multi-depth boxes tested.

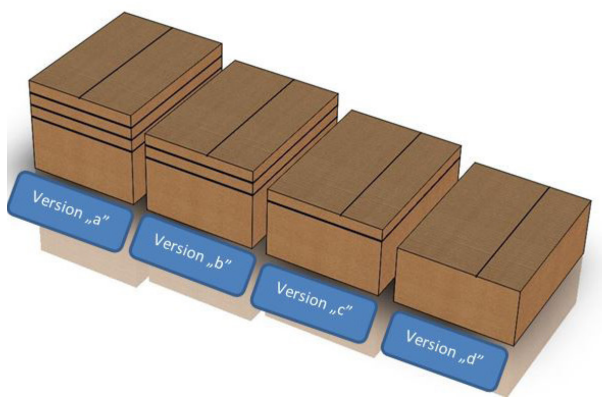

Figure 2: The tested samples in half pallet size

In this case, it should be noted that the overlapping will be found when the height of the box changes at creasing lines, which can affect the results of compression strength. This overlapping can be seen on Figure 3 after cutting the proper height. Of course, there was no overlapping in the control sample.

Figure 3: Overlapping at the first creasing line

3.0 RESULTS AND DISCUSSION

Table 2 shows the results of compression testing compared to the relative mean value of control samples. Each testing instance was conducted at different creasing lines with five samples. Finally, a total of 100 samples were tested together with the control samples.

Table 2: Results of the Box Compression Tests

			Type 1	Type 2	Type 3	Type 4	All
			Compression strength value % of the control value [%]				
Samples tested at different creasing lines [pcs]	3	mean	82	75	86	85	**82**
		n	5	5	5	5	20
	2	mean	76	79	83	79	**79**
		n	5	5	5	5	20
	1	mean	70	75	91	78	**79**
		n	5	5	5	5	20
	0	mean	101	99	104	88	**98**
		n	5	5	5	5	20
	All	**mean**	**82**	**82**	**91**	**83**	85
		n	20	20	20	20	80
Mean for controls (zero creasing, original height) [N]			6750	5625	8500	9201	7519

Table 2 shows that the average compression strength reduction per each type was about 20%, except for Type 3, which has decreased only 9%. The half-pallet sized boxes (Type 2 and Type 4), independently from the paperboard material, show a similar compression strength decreasing. In contrast, the full-pallet sized boxes (Type 1 and Type 3) have a 9% difference. The highest reduction of compression strength for all measurements could be found in the case of Type 1 and 1 creasing line.

Observing the effect of creasing lines, the average reduction was most significant in the case of the testing of boxes with 2 and 1 creasings. The least significant reduction (98%) could be observed at the boxes with zero creasing line. Naturally, in this case, the height of the box was the smallest. As it was mentioned above, the height can affect the compression strength of the box. It is also proven again in the cases of Type 1 and Type 3, where the compression strength values were 101% and 104% compared to the control sample.

The results of the measurements were first analysed using a 2-way analysis of variance. The variables were the box size and the numbers of creasing. In the cases of Type 1 and Type 2, as expected, the box size, the numbers of creasing and their interaction were significant ($p<0.001$). On the other hand, in the cases of Type 3 and Type 4, the box sizes were not significant ($p<0.05$), but the number of creasings ($p<0.001$) and the interaction were significant ($p<0.05$).

Table 3: Regression results of multi-depth boxes

	Coefficients		
	Intercept ('y' axe)	***Creasing nr ('x' axe)***	***Adjusted R-Square***
Type 1	6007.3	337.2	23%
Type 2	5181.1	383.0	55%
Type 3	8557.7	539.0	56%
Type 4	7702.4	72.9	1.8%

Individual regression analysis was also performed. It showed a weak relationship between the compression value and the number of creasings for Type 1-3. However, the regression analysis did not indicate a significant relationship between the compression value and the number of creasings in the case of Type 4. This phenomenon could be attributed to the different perimeters of the box types. According to the McKee-formula it could be easily foreseeable that a box with smaller perimeter has got a greater measured BCT value. That is the reason why the Tpye 4 was affected least by the creasing lines, cause beside the relatively better board quality it had got the lower perimeter too. Table 3 shows a weak relationship between the compression value and the number of creasings. The adjusted r-square values ranging from 23 to 56% indicate an adequate fit to a linear model. For example, each additional creasing line predicts an approximately 337 N compression strength decrease of the box, which has the same geometrical dimensions and material type as Type 1. The measured values and regression plots can be seen in Figure 4. This figure contains all of the 80 measured results of boxes with creasing. At this point, it should be noted that the measured values are not perfectly fitted as linear, which can be proved with the lower adjusted r-square prediction of Table 3. This way, for example, the measured box compression values with 1 creasing are lower than those with 2 creasings in the cases of Type 1 and Type 2.

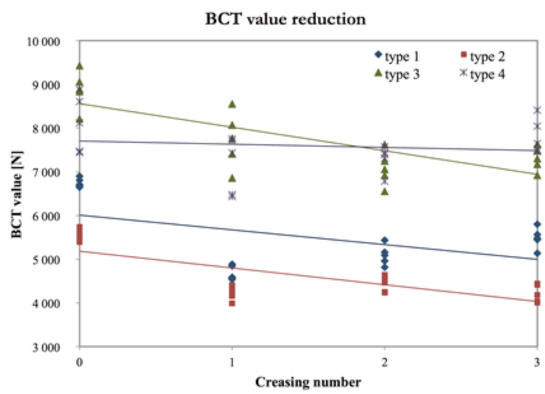

Figure 4: Regression plots of multi-depth boxes

It has to be recognised by the readers of this paper that the compression strength based on numbers of creasing lines can be significantly affected by the quality of the paper and/or the paperboard. But the results of this study can be recommended for the simulation of stacked corrugated boxes with creasing(s) in the logistics process.

4.0 CONCLUSIONS

Based on the results, the following conclusions can be drawn:

- The maximum experienced compression strength reduction was 30%, which is less than the predicted value. This reduction can easily be compensated during the design process with a safety factor or by substituting for a different (better) paper quality.
- There is no significant difference in compression strength between boxes with 3 or 2 creasing lines, so in order to maximise versatility, the use of 3 creasing lines is recommended during production.
- In the case of half pallet boxes with better quality materials, the creasing does not influence weakening that much, so the proper choice of material quality in case of lower sized multi-depth boxes is going to lead to less excursion.

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